SATELLITE TO SATELLITE RADIO OCCULTATION SCIENCE AT MARS, E.R. Kursinski, .Y. E. Bar-Sever, W.M. Folkner, and L. J. Romans, Jet Propulsion Laboratory California Institute of Technology, Mail Stop 238/600, 4800 Oak Grove Drive, Pasadena, CA 91109. E-mail: erk@cobra.jpl.nasa.gov

We present a requirement and feasibility analysis for probing the Martian atmosphere with occulting radio science. The opportunity for occultation science around Mars arises due to the anticipated proliferation of orbiting assets in the coming years and, in particular, the proposed Mars Network of orbiting satellites for navigation and communications. Since every spacecraft around Mars is expected to have a capability to transmit on the 8.4 GHz DSN downlink band, equipping other Martian satellites with the ability to receive this frequency will potentially create many occultation opportunities. Accurate measurements of the Doppler shift due to the refractive index of the atmosphere will enable determination of vertical profiles of density, pressure and temperature versus radius and geopotential. Additional transmit and receive capability at the 22 and 183 GHz water lines will enable accurate vertical profiles of water vapor. Robust occultation science will be helpful in answering many questions about the makeup and nature of the Martian atmosphere, including:

- Quantitative understanding of the present climate and of its controlling physical mechanisms (e.g. dust storms and polar radiative balance)
- Quantitative understanding of atmospheric transport, particularly into and out of the polar regions
- Inference of surface sources and sinks of atmospheric water vapor

Conventional passive sounders measure atmospheric temperature as a function of atmospheric pressure. A radio occultation experiment like MOM measures total refractivity, which is proportional to density and therefore a function of both temperature and pressure, as a function of altitude. The occultation-derived profiles of pressure vs. radius (and geopotential) allow direct estimates of geostrophic or gradient winds to be obtained much more directly than those derived with infrared sounders and the thermal wind equation. This is especially important for determining wind speeds near the surface, where the winds are usually assumed to be zero in the thermal wind approach. This has obvious relevance to studies of dust storms. Occultation-derived surface pressure allows one to literally "weigh" the atmosphere, and thus follow the atmospheric mass as it changes with seasons. The radio occultation technique provides vertical resolution and accuracy significantly beyond those of passive techniques capable of characterizing a wide variety of Martian atmospheric phenomena including synoptic scale weather, boundary layer meteorology, atmospheric waves and turbulence, dust storms and surface fluxes of moisture. It provides an absolute measure of the geopotential of pressure surfaces for determining atmospheric dynamics, characterizing the mass exchange between the atmosphere and polar ice caps and providing pressure versus geopotential reference needed to interpret radiances from passive remote sensing instruments. The extremely accurate temperature versus pressure profiles can determine where pressure equals the saturation vapor pressure of CO_2 such that CO_2 is condensing to form the ice caps. The water vapor sensing capability will characterize the atmospheric portion of the Martian hydrological cycle, water vapor profiles accurate to 1-10%. With its high accuracy, high vertical resolution of ~100 m and global and long term coverage, these observations will characterize the Martian hydrological cycle spanning diurnal to interannual temporal scales required to infer surface sources and sinks of Martian moisture.

The required instrumentation consists of an X-band transmitter (standard on all spacecraft at Mars) and receiver at 8.4 GHz, and a water vapor sounding transmitter and receiver at 22 and possibly 183 GHz driven by an Ultra-Stable Oscillator (USO) crystal frequency reference. The 8.4 GHz capability yields vertical profiles of density, pressure and temperature versus height with a vertical resolution of ~400 m or better which spans the surface to 50-60 km as well as electron density profiles in the ionosphere.

The 22 and 183 GHz transmitters and receivers will measure atmospheric water vapor absorption profiles yielding a sensitivity of 10 to 1000 ppmv and vertical resolution of 100 to 400 m whenever the pair of satellites see one another across the limb. The insensitivity of the higher frequencies to the ionosphere also extend the vertical range of the density, pressure and temperature profiles at least 2 scale heights beyond the X-band system. They may have some utility as passive radiometers as well. Water line instrumentation for such measurements are presently under early phases of development in NASA's Instrument Incubator Program (IIP) for Earth-borne applications.

The received X-band, 22 and 183 GHz signals will be translated down to lower frequencies where receivers derived from the Earth-orbiting GPS occultation

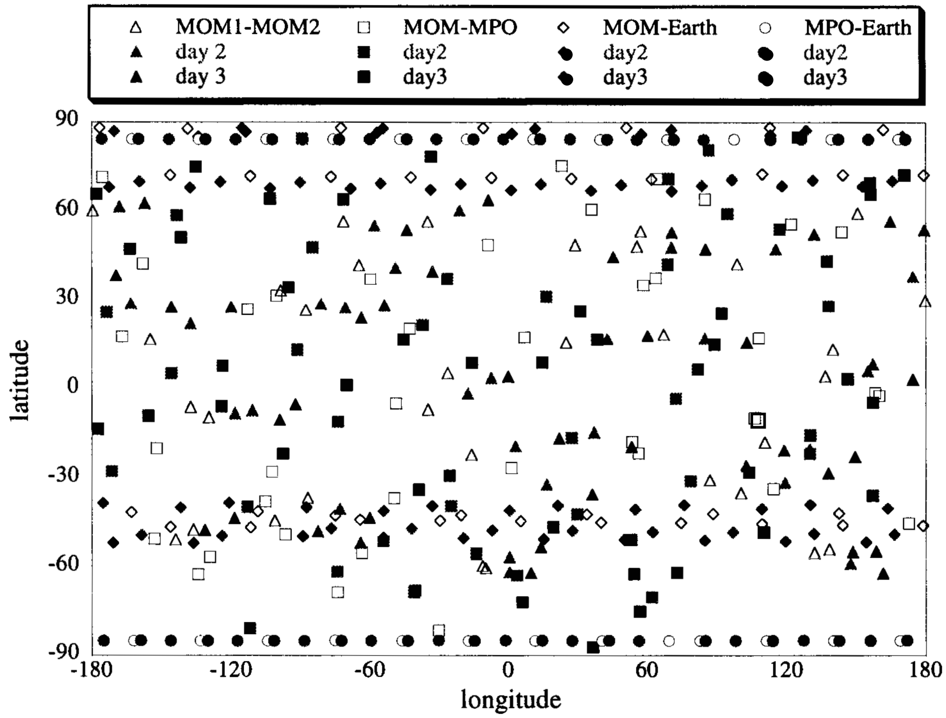

Figure 1. Location of occultation measurements over a three-day period. Occultations occur between the two Mars Occultation Micromission orbiters (MOM1, MOM2), between either of these orbiters and Earth (MOM-Earth), occultations between either of these orbiters and an assumed low-polar orbiter (MOM-MPO), and between the assumed polar orbiter and Earth.

receivers will perform the necessary signal processing. Two antennas (one fore and one aft-facing) will be provided at each frequency. These antennas will be broad-beam to eliminate the need for antenna pointing.

In designing the orbital configuration of the orbiting assets, attention must be paid to optimal occultation geometry. This typically calls for the orbiting assets to be in retrograde orbits with respect to each other, and for orbit selection that promotes randomness in occultation coverage. An example of the possible coverage is shown in Fig. 1. For this calculation, two Mars Occultation Micromission (MOM) orbiters were placed into elliptical orbits with period of three hours, inclination 60°, moving in opposite directions. An auxiliary orbiter was assumed capable of transmitting to the MOM satellites and to the Earth. The number of occultations with these assumptions is 124 per day. Over the three day period shown the globe is reasonably well sampled. The occultations between the satellites and the Earth fall in distinct latitude bands, with those to the polar orbiter at high latitude. In general the choice of orbits will represent a compromise between cost of orbit insertion, shorter period for more occultations versus higher apoapsis for better view of auxiliary orbiters, etc.